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The Ranger Project

O.Liepack

NASA/Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

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O.G.Liepack
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Abstract:

In preparation for the first landing of a human on the Moon, several precursor missions were necessary to investigate its unknown environment. It was only 2 years after the launch of the first Soviet Satellite Sputnik, that Luna 1 passed the Moon. Ten months later the first Soviet spacecraft impacted on the Moon. All of these missions, whose objectives were not always scientific, were tentative steps towards landing a person on Earth's natural satellite. The Ranger missions 1 thru 9, which were flown from 1961 to 1965, were some of the first spacecrafts to have scientific objectives as well as technical experiments. In addition to providing Lunar environmental information such as radiation measurements, they captured the first high-resolution pictures of the Lunar surface.

The purpose of this paper is to compare Ranger different versions, including their payloads, orbits and their scientific results. The planning and operations of those missions, that took place in the beginning of spaceflight, will be briefly described.

Introduction

"The Ranger Project was a landmark in the development of this nation's capability for flying unmanned missions to the Moon and the planets. Many of the space sciences and technologies that were later to prove so important to both soft-land and manned Lunar missions, and the automated exploration of the near planets, were conceived and developed out of the Ranger experience.

In this sense, Ranger was a pioneer effort - a fruitful and highly fertile seedbed out of which the United States thrust into deep space had many of its origins...." Dr. W. H. Pickering [1]

Background

The development of rockets and the start of the sophisticated scientific analysis of the Moon began at the end of the 19th century. As in the science fiction books of Jules Verne or Hans Dominik, men were dreaming about traveling to the Moon. The reasons for this can be found in the fact that humans are adventurers and are striking to greater heights. The early development of war rockets in the 18th century encouraged scientists and engineers to think about the possible use of rockets for space travel. The dream of reaching the Moon was at least theoretically proven, once Walter Hohmann published his book "Die Erreichung der Himmelskörper" (The Attainability of Celestial Bodies) in 1925, which still teaches engineers the basics of spaceflight mechanics. The development of rockets in the great World Wars of this century caused not only destruction and suffering, but also created an important tool which enabled humans to reach for the skies. The only question after the WWII, when space dreams became more and more feasible was: what should we send up? The payload of rockets after WWII were scientific instruments measuring the upper-atmosphere of the Earth, which couldn't be reached easily and only by great effort with planes. Those tests were conducted by the US Army with V2 rockets. There was no distinction between engineers and scientists during that time period, and important steps for unmanned space vehicles were undertaken. Major problems were discovered during these tests, such as interference between scientific instruments and the transmission of their measurements to ground stations [2]. Granted, today's projects benefit greatly from the research which began 50 years ago.

The "Red Socks" and Early Moon Missions

The United States looked for opportunities to compete with the Soviet Union after Sputnik 1, which was launched in 1957. Proposals for that competition came in from all over the country such as testing an H-bomb on the surface of the Moon for observing the results of the explosion, "A tiny crater would remain as a mark of man's work on the Moon" [1]. The birth of Ranger was in November 1957, when Dr. W. H. Pickering, Director of the Jet Propulsion Laboratory (JPL), and Dr. L. A. DuBridge, President of Caltech, presented a proposal for a Moon-probe to the Secretary of Defense, Neil McElroy. The proposal had the title "Red Socks" and suggested nine lunar flights with two different kinds of spacecraft. The technical objectives were to take images of the far side of the Moon and to refine space guidance and communication techniques. The major objective of that proposal from November 1957 was to have a quick and impressive answer to Sputnik. The proposal declared it "imperative" for the nation to "regain its stature in the eyes of the world by producing a significant technological advance over the Soviet Union" [4]. Early in 1958 the newly established Advanced Research Projects Agency (ARPA), realized that lunar missions would advance space flight technology and "determine our capability of exploring space in the vicinity of the Moon, to obtain useful data concerning the Moon, and to provide a close look at the Moon". The new lunar program would consist of 3 US Air Force launches directed by ARPA, whereas the Army had 2 missions scheduled to be designed, built and tracked by JPL. The ARPA program generally became known as the "Pioneer Program". Two of the Air Force missions failed during the launch, however the third, although not able to reach escape velocity, delivered important information about the newly discovered radiation belts around the Earth. Based on these and the Explorer measurements, JPL's two spacecrafts had to be re-engineered so that the scientific system, such as a slow-scan television camera, could be shielded appropriately against the strong radiation. On December 6, 1958, the Army and JPL launched their first lunar probe, known as Pioneer 3. This spacecraft, like Pioneer 1, did not attain escape velocity and reached an apogee of only 101,000 km. However, enough important data about Earth's magnetosphere was obtained, that Dr. van Allen proposed to exchange the camera system of Pioneer 4 for other radiation instruments. This proposal was approved and the spacecraft left Earth's gravity field without any problems on March 3, 1959. This was the last flight of the ARPA lunar program, which was unable to reach the objective of obtaining high resolution images of the Moon. It was Luna 1 of the Soviet Union, launched a few weeks prior to Pioneer 4, that became the first spacecraft to fly close to the Moon. And it was Luna 3 who took the first pictures of the Far Side of the Moon [4].

The US American Lunar program was then conducted by the newly established National Air and Space Administration, NASA. Space science, which included planetary exploration, was one of the main branches of the newly established NASA. Members of that branch had only limited available technology, unlike the atmospeheric scientists. They developed a huge variety of instruments over the last 20 years, for electromagnetic field and charged particle measurements. In January 1959 Homer Newell, Assistant Director of Space Science at NASA Headquarters, formed a working group on Lunar Exploration whose goal was to be a forum between scientists at NASA and the academic world. It would recommend scientific activities for orbiters and lander missions.

That scientists and engineers would come together and be heard by NASA Headquarters from now on, can be seen as one of the most important steps in the exploration of the Moon. By the end of 1959, NASA published its "Lunar and planetary exploration program", which included "Lunar and planetary probes, orbiters, rough landings, soft landings, and mobile vehicles for unmanned exploration" [1]. Another question still waiting to be answered was: which rocket could be used to transport a new space vehicle to the Moon ? During that time, JPL was mandated by NASA to conduct unmanned deep space exploration, which included the Moon. Clifford Cummings from JPL suggested a name for the Lunar missions: RANGER. That name was immediate accepted at the Laboratory and at NASA [4].

The Birth of Ranger:

In late 1959 the decision was made to take the Air Force Atlas-Agena B rocket as a launch vehicle for Ranger. The advantage of that system was its capability to restart the second stage in orbit. A Survey Team was formed, which suggested five Agena flights to fulfill NASA's objectives of a close-up reconnaissance of the Moon and the landing of an operating scientific instrument on its surface. The Ranger Project consisted of four groups. At the east coast was the recently formed NASA Headquarters. Caltech's JPL was the contract manager for the Project Ranger. A key player was the Lunar Program Director Clifford Cummings. He announced the 35 years old James Burke as the Ranger Project Manager. JPL was responsible for three out of four of the Ranger-system components: the spacecraft, the deep space tracking and control network, and finally the operations [4]: The third partner was the Army's von Braun missile team (since 1960 NASA's Marshall Space Flight Center) which contributed knowledge in rocketry [5]. The fourth partner was the Air Force with its launch vehicle contractors. Each group had its own identity, organization charts, bureaucratic independence and work atmosphere. The newly formed structure was too complicated and the geographical distances of the major partners were too far, (e.g., requests from JPL concerning the Agena launch vehicle provided by the Air Force had to go via NASA Headquarters and an answer had to come back through the same channels). Due to those differences and a not so clearly defined hierarchy, changes in responsibilities and management structures were undertaken in 1961. In January 1961 Lockheed delivered a modified spacecraft adapter and nose fairing for assembly testing. Due to misunderstandings and poorly defined management structures, the Ranger Project fell behind. This caused the first flight to be postponed until 1962, one year late [4].

The Ranger Spacecraft Block I, II

Early studies of spacecraft for planetary exploration at JPL began in 1959 under the leadership of Albert R. Hibbs. Major problems were identified in the areas of communication and spacecraft stabilization. The basic design of the Ranger spacecraft was based on early studies, which was basically a three-axis stabilized structure in which the spacecraft bus and the scientific instruments were accommodated. It included foldable solar wings, expandible booms and a high gain antenna pointed to Earth. The key question arose when the scientific objectives were defined: what scientific instruments should and can be accomodated. Those questions were discussed within NASA Headquarters Space Flight Programs Office, which was led by Homer E. Newell. He saw quickly that the success of spaceflight missions would be dependent upon the support of the scientific community. Therefore he invited scientists from inside and outside the agency, to propose instruments for different planetary missions. Based on Vega studies, early in 1960, NASA approved a list of experiments for five Ranger flights which included magnetospheric science experiments, a television camera and a seismometer.

The plan was to conduct two test flights, with the so called Block I, carrying sky science experiments. The following three flights, Block II, would photograph the Moon, measure its gamma-ray emissions and deposit seismometers on its surface. In February 1960 Cummings issued a list to JPL with Project Ranger's objectives, which showed the order of importance: 1) develop the spacecraft technology, 2) maintain schedules, 3) establish industrial support for NASA-JPL planetary flight missions, and 4) support science [4].

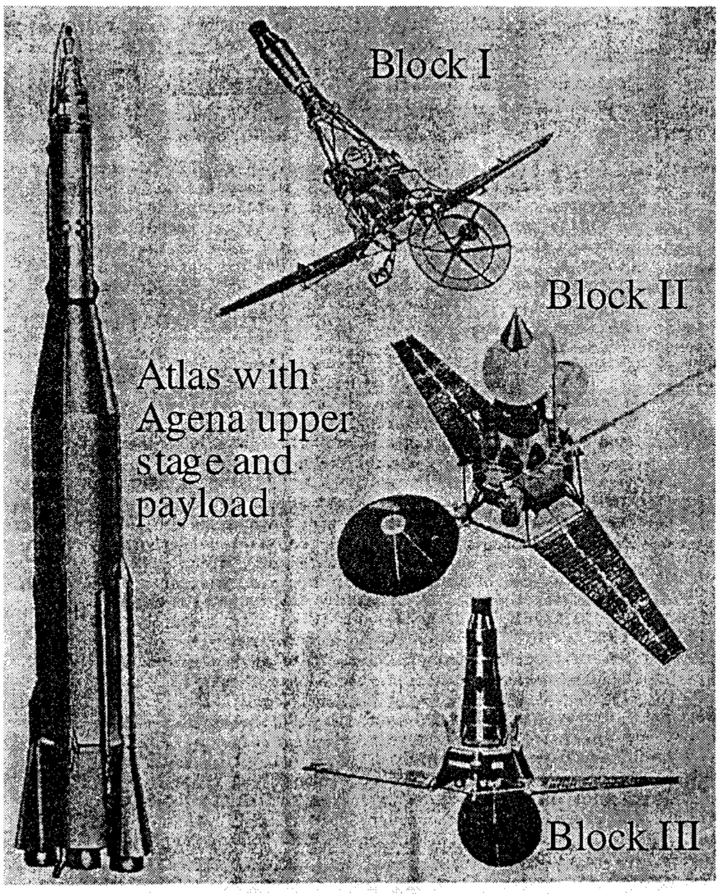

Fig 1. Atlas, Blocks I, II, III

During the design of the spacecraft, engineers were confronted with the harsh environmental conditions that would be present during lunar missions. They decided to use solar panels and batteries to provide approximately 100 to 150 W for the various spacecraft systems, including the scientific experiments. Solar heat and the heat from the instruments were radiated into space via the structure which was made of aluminum, magnesium alloys and special coatings. The spacecraft's health was observed via telemetry during the entire flight. The attitude control was determined with photoelectric cells so that maneuvers with cold nitrogen gas could be performed.

In mid 1960, while already beginning to select contractors to produce components for the spacecraft, problems were encountered with the mass of the Block II final design. In July 1960, Lockheed presented new calculations for the ascent trajectory of the launch vehicle. These calculations showed that the original Ranger spacecraft design, based on General Dynamics calculations, was 34 kg too heavy. The launch date for Block I in July and October 1961, as well as the date for Block II in the first half of 1962 were questionable. JPL engineers tried to reduce the mass of both Blocks by replacing high density material with low density magnesium and other alloys. Further mass reductions were achieved by drilling holes into boxes or other massive parts, so that "parts of the craft began to resemble Swiss cheese" [4]. In December 1960 an agreement was made on the final trajectory of the flight, but it would take another 6 months before a third contractor issued the final set of trajectories, which allowed them to determine the approximate weight of Ranger. In the meantime Burke and the engineers at JPL took all efforts in reducing the spacecraft's mass to meet the preliminary calculations. They removed backup systems, like the low power transmitter, a redundant set of attitude control gas jets, as well as a set of engineering instrumentation gyroscopes. On May 28, 1961, the final trajectory calculations for the Ranger mission were issued and with it, the final numbers for the spacecraft's mass. "Burke glumly reported that an additional 74 kg were available for Block I and 52 kg for Block II spacecraft... This increase in allowable mass was unexploitable at this late date." [4]. Ranger 3, the first Block II spacecraft, had a mass of 327 kg. Ranger 1and 2 (Block I) at that time already at the Cape, had a mass of 304 kg. Those numbers were made possible by taking out important redundant systems which could have improved the reliability of a new vehicle in an almost unknown environment.

Preparing of Block I

The assembly and testing of Ranger 1 and 2 took place from June 1960 to August 1961. In addition to the updates in the managerial structure, JPL's engineers were confronted with new aspects, like preparing a new spacecraft for a long journey operated by an almost new ground support system. Three different versions of the spacecraft were assembled: a spacecraft mockup to verify mechanical aspects; a thermal control model, which was tested in a vacuum chamber where flight conditions were simulated; and finally, based on the experience of the two previous models, the proof test model. JPL followed a new test procedure, rather than testing only subsystems, the entire mission was simulated. Entire sets of commands, known as sequences, were sent from the ground stations to the spacecraft, where those events were validated. The second test consisted of simulating the environmental conditions throughout the mission, including launch. For those purposes a new infrastructure was necessary at JPL. By mid 1961 a spacecraft assembly facility and the environmental laboratory were finished. Unfortunately tests with Blocks I and II could not be performed there because the vacuum chamber wasn't completed until November 1962.

In September 1959, NASA received a letter by the National Academy of Science informing them that all spacecraft missions have to follow the guidelines set by the International Council of Scientific Union (ICSU). This groundrule required the sterilization of all space probes, that might impact on another celestial body. The purpose of the rule was to prevent the transport of microorganism from Earth to another body where they could reproduce themselves or make it impossible to discover and examine extraterrestrial life forms. On May 25, 1961, NASA approved the procedure for sterilizing the Ranger probes. It consisted of a three step procedure: 1) heat all spacecraft components for 24 hrs. at 125° C, 2) clean all surfaces after assembling the craft in the new hall, 3) "soak" the entire spacecraft in ethylene oxide gas at the Cape prior to launch. These additional new requirements were formulated late in the development phase and caused redesigns and delays in the schedule. Furthermore, the long-term effects of the treatments on the systems were not known [4,6].

In the meantime other important facts had to be accomplished: tracking of the spacecraft, retrieving of its engineering and scientific data, and the capability of sending commands. All these tasks were managed within three different components: 1) a Deep Space Network, 2) Mission Operations, 3) Launch Operations.

The Deep Space Network (DSN) consisted of radio tracking, telemetry and command stations at three different locations around the Earth. All these had to be developed and built within a short period of time. In 1960 Dr. Eberhard Rechtin from JPL was announced as the Director of the Deep Space Instrumentation Facility. His group developed and built, with the help of the US State Department, three almost identical stations, the first at Goldstone (California, USA), the second at Johannesburg (South Africa) and the third at Woomera (Australia) [3]. The decision for the different sites was to enable the operators at JPL to monitor and send signals at all times. In those early days, the ground communication between sites was sometimes poor, but never caused any serious problems. The uplink of commands from the Earth to the spacecraft was provided by a 10 kW transmitter, whereas Ranger's transmitter sent the signal back to Earth only with a power of 3 W. At each site 26 m steerable antennas were installed, so that on July 4th, 1961 NASA declared DSN operational for deep space missions [4].

The second new task which had to be accomplished was the creation of a Space Flight Operations Center, to be located at JPL. All telemetry data sent from the spacecraft and received by the three different ground stations were evaluated at this center. Personnel worked 24 hours a day to monitor the status of Ranger as well as to prepare commands, which were sent to the DSN and then radiated to the spacecraft [6]. Like the DSN, NASA's Space Operations Center was declared operational in mid 1961. It would control the spacecraft once it was injected into its transfer orbit [4].

The launch operations were located at Cape Canaveral and run by the US Air Force, which in the beginning was responsible for the Atlas-Agena B launch vehicle. After long discussions NASA was finally successful with the argument that they are the controlling agency of Ranger and that they should have the full responsibility from launch through the end of the mission. The Air Force agreed to furnish the launch vehicle and to give their mobile antennas for tracking the spacecraft during ascent. All these changes were accomplished in early 1962, at a time when the first Atlas, Agena and Ranger arrived at the Cape [4].

Flights of Block I:

Ranger 1 and 2 were scheduled to be launched in 1961 to fulfill various objectives. It would demonstrate the engineering capabilities of the spacecraft, the operations support at JPL, the tracking capabilities of the new Deep Space Network, the reliability of the launch vehicle and the performance of some of the scientific instruments. Each spacecraft would first be launched into a low Earth orbit. The Agena B stage would then transfer the vehicle into a highly elliptical orbit with an apogee of one million kilometers, whereas the perigee remained at a few hundred kilometers. That would give engineers the chance to operate their spacecraft under conditions which were expected for Block II on its way to the Moon. Scientists would have the unique opportunity to measure the magnetosphere as well as to investigate space environmental conditions. The scientific package of Block I was finalized in mid 1960. It contained 1) solar plasma detector, 2) magnetometer, 3) trapped radiation detector package, 4) ionization chamber, 5) cosmic-ray telescope, 6) Lyman alpha scanner, 7) micrometeorite detector. Not listed, but integrated, was an instrument, called Vela Hotel, of the Atomic Energy Commission for detecting Röntgen- and gamma-rays [4].

After several launch delays, caused by electrical malfunctions, leaks and ground control problems, Ranger 1 was finally launched from Cape Canaveral by an Atlas-Agena B on August 22, 1961 [4]. Soon after the launch, ground stations at Goldstone and in South Africa received telemetry from the launch vehicle, indicating that the second burn of the Agena B had gone improperly. With a perigee of 168 km and an apogee of 501 km altitude Ranger 1 was in an extremely low orbit, for which the Deep Space Network system was not designed. Only some stations were able to cover the flight of the spacecraft which was in a totally unexpected and useless orbit. It passed every 90 minutes into the shade of the Earth, so that its batteries couldn't get charged long enough to provide sufficient energy to the subsystems. In addition, Ranger 1's telemetry system was not able to sustain the appropriate alignment to the Sun, and the spacecraft tumbled in space. After only 8 days, Ranger 1 reentered Earth's atmosphere on August 30, 1961, with only a few scientific and engineering results [4].

Ranger 2 was scheduled to be launched at the end of October 1961. And similar to its predecessor, the launch was delayed due to problems with scientific instruments as well as with the launch vehicle. Although several problems were solved after Ranger 1, Ranger 2 had the same misfortune. At this time the burn of the second stage didn't occur at all, thus the spacecraft reentered the atmosphere after 19 orbits on November 19, 1961. However, it separated properly from the Agena and all activities, like the deployment of the solar panels and the high-gain antenna, were performed correctly [1].

The Air Force worked hard on changes on the Atlas-Agena B in the upcoming months. Nevertheless, NASA, who was in the beginning only the customer, had decided to take more responsibility in the launch and its preflight testing. Based on problems that occurred during the countdown, JPL decided to change its procedures for checking and maintaining science instruments onboard the spacecraft in the prelaunch phase [6].

Block II:

In the beginning, the plan for the Ranger Project consisted of two different kinds of spacecraft. After the two engineering test flights of Block I, the Block II series would consist of three flights to the Moon expressly for scientific purposes. After performing a direct flight including a midcourse maneuver, it would then take pictures of the Moon and deposit a seismometer on the surface. The seismometer capsule was supposed to be released from the Ranger spacecraft 24 km above the surface and impact, decelerated by retro-rockets, with a residual velocity of 61 m/s. A radar altimeter would trigger the separation of the capsule based on the distance to the surface. The life-time of that experiment was designed for two weeks, for which a battery pack would provide enough energy for the experiment and communications. In addition to the TV camera, a gamma-ray spectrometer for surface composition analysis completed the scientific package of Block II. New NASA guidelines in support of Apollo, created the need for some late changes, one of which was the downlink of the radar altimeter data [4].

Like its predecessor, the design of Block II was based on the wrong trajectory calculations, so that several redundant spacecraft systems had to be removed to reach the erroneous allowable launch mass. In addition to the mass requirements, Burke and his colleagues at JPL had to follow the new guidelines of planetary protection. Although some waivers for certain subsystems were given, JPL was still concerned that the heat sterilization might harm the different spacecraft parts which could result in an anomaly [7].

Although problems with the seismometer occurred right before delivery to the Cape, mutual efforts from all sides assured a flight readiness for a launch window between January 22 through January 26, 1962 . A target close to the equator and west of the lunar prime meridian promised to fulfill both photometric and tracking requirements. A leak in the Altas fuel tank was repaired on the pad, so that the Atlas-Agena B with its payload, Ranger 3, was ready for lift off on January 26, 1962. Ground operations lost control immediately after the launch, and the vehicle rose into the sky under control of its autopilot. Ranger 3 was injected, into an useless orbit, where it successfully separated from the Agena B. The solar panels, gamma ray-spectrometer and high-gain antenna deployed flawlessly. Finally JPL had its first operating Ranger spacecraft on a deep space trajectory. Quick calculations showed, that the engines of the Atlas burned too long, which meant Ranger would pass ahead of and below the Moon at a distance of 32,000 km. Burke decided to perform the midcourse maneuver and to take images during the unplanned flyby. The placing of the seismometer on the surface was no longer possible due to the distance of the Moon.

Unfortunately, the first midcourse maneuver of the space vehicle moved Ranger in a direction that was the mirror image of the one expected. A fast analysis showed an error in the command coordinates, which they were able to fix right before the terminal maneuver. During the terminal maneuver Ranger's radio signal weakened and the DSN on Goldstone was no longer able to track the spacecraft. The reason for that was the unexpected mispointing of the high-gain antenna which no longer pointed to the Earth. Ranger's central computer and sequencer had failed, the Sun and Earth could not be acquired by the sensors and the vehicle continued to turn. The camera system started to take images, but was unable to target the Moon. Ranger 3 passed the Moon at a distance of 37,000 km and was able to be tracked until January 31, 1962 [4].

Ranger 4 arrived at the Cape and was made ready for the launch window on April 21 through 26, 1962. JPL engineers analyzed the data from Ranger 3, so that changes could be implemented to the new mission. The errors, which caused the wrong change during the midcourse maneuver as well as the problems with the launch vehicle, were solved. Only the Ranger 3 malfunctions of the central computer and sequencer, were not really determined. Some engineers believed that they were caused by the heat sterilization.

Ranger 4 launched on Saturday, April 23, 1962. With the improvement in commands, upgrades to the launch vehicle, and the changes and additions to the so far successful deep space operations, everybody felt confident that this mission would be a success. The flight of the Atlas and the maneuvers of the upper stage seemed correct. However, 23 minutes after launch, Ranger's transponder was transmitting with the correct frequency, but the signal didn't contain any telemetry. Without the telemetry, JPL flight controllers couldn't determine the condition of the spacecraft. Based on the fluctuating transponder signal, the engineers believed that the high gain antenna and the solar panels were still in the original launch position and that the spacecraft was tumbling. Although Ranger 4 was on a perfect trajectory, it would hit the Moon without a midcourse maneuver, the vehicle was blind and wouldn't except signals from the Earth. Hours before impact, the battery of the transponder was drained and the weak transmitter signal of the seismometer experiment was the only evidence of Ranger 4. The impact occurred just at the edge of the far side of the Moon, and the mission was announced as a partial success [4].

The discussion of which role the Ranger Project would have to play in the development of the Apollo project started right after Ranger 4. Should its objectives be focused only on science, or should important questions for the development of Apollo be solved? Suddenly JPL's role in the development of Ranger was also in question. The discussion resulted in the announcement of two new projects, Lunar Orbiter and Surveyor.

In the meantime JPL's engineers were busy trying to solve the problems which caused the partial failure of Ranger 3 and 4. The reason for the failure of the central computer and sequencer couldn't be determined. It was believed in Ranger 3 that a short-circuit which occurred during the separation of the spacecraft from the Agena was responsible for the failure. Hardware as well as organizational changes in the ground support were made. The heat sterilization process didn't change, although engineers believed and proved that it would degrade the flight hardware's performance [7].

The changes were made and Ranger 5 was launched from Cape Canaveral on October 18, 1962. All launch systems were nominal and the spacecraft was tracked continuously during its flight. After the separation from the Agena upper stage, Ranger 5 deployed its solar panels and high-gain antenna and was stabilized in orbit. Everything looked fine up to this point. Suddenly the temperature in the central computer rose and the electrical power from the solar panels was lost. Ranger 5 switched to battery power and turned on the gamma-ray spectrometer as planned. Unfortunately problems with the ground stations occurred at exactly that same moment, and ground controllers couldn't obtain an accurate health analysis of the spacecraft. Knowing that the mission was almost lost, Burke decided to perform engineering tests. A midcourse maneuver was uplinked and acknowledged by the spacecraft. However, electrical shorts caused the telemetry signals to the ground to, and the gyroscopes for the attitude control to stop working. After the battery ran out of power, the deaf and blind Ranger 5 passed the Moon at an altitude of 720 km. The seismometer signal, again the only evidence of the existence of the spacecraft, was tracked for a couple of more days. Then it went silent. All 3 flights of Block II were unsuccessful. The discussion concerning the predecessor to Block III, involved different parties and the entire project culminated right after the failure of Ranger 5 [4].

Block III:

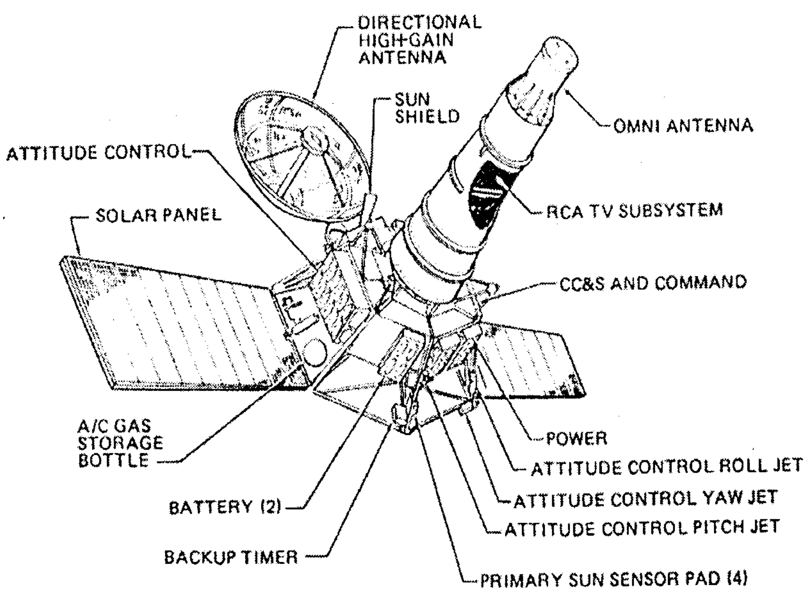

Fig.2: Block III

The first ideas for a third Block for Ranger were formulated in July 1961. They were brought up when the Apollo Project was announced and NASA HQ asked for support of the lunar lander design. The biggest question was: what does the Lunar surface look like? Pictures taken from several different TV cameras mounted on a Ranger spacecraft would answer that basic question. When the science objectives of Block III were specified, several instruments were included, like sky science instruments and other remote instruments for surface investigations. Block III would consist of 4 flights, Ranger 6 through 9, which would be launched between 1962 and 1963. The idea was to use a modified Block II structure and to add a couple of more instruments to it.

Several review boards of the participating agancies were created to investigate the reasons behind the failures of Ranger 1 through 5. JPL's Board of Investigation recommended: 1) to reorganize the management structure, 2) to abandon the heat sterilization of all components, 3) to assign some workload to contractors, 4) to assign Atlas-Agena related issues entirely to either NASA or the Air Force, 5) to restate objectives of the Ranger Project and 6) to eliminate objectives not directly related. NASA agreed to the suggestions, but demanded others as well: 1) replace Jim Burke as a Project Manager, 2) fly only TV systems as a scientific payload, 3) install more redundant systems, 4) reformulate NASA's Lunar Program office, 5) modify and create new test procedures [4].

The new Ranger Project Manager, Harris Schurmeier, was announced on December 18, 1962, just four days after Mariner's 2 successful flyby at Venus.

Guidelines for Block III, given in early January by Schurmeier were:" A few TV pictures of the Moon, better than those taken from Earth, is the only mission objective. No advanced development experiments or additional scientific instruments will be carried." [4] Burke applauded. Redundant engineering systems replaced the previously considered sky science instruments, which consumed a mass of 22.5 kg. Finally Ranger was no longer restricted in mass and power. Scientists around the country agreed, after long debates,that the Ranger project would become a success only when the spacecraft's capabilities and functions could be advanced by the replacement of science instruments with the necessary engineering devices. Knowing that Ranger 6 through 9 would be another engineering project as well as an important step for the Apollo program, they finally agreed to NASA's suggestion for a future Block IV which would carry their instruments [4,6].

In February 1963 NASA and JPL came up with some major changes to the spacecraft, the payload and the launch vehicle. The spacecraft would carry an additional battery, so that a minimal operation of the spacecraft would be independent from the success of the solar panel deployment. Furthermore, redundant systems for the timer and strings were integrated. The payload would consist of two full-scan and four partial-scan cameras which would be switched on 20 minutes before impact for thermal reasons. The data taking mode would be from minus 10 minutes until impact. An important organizational change occured in the summer of 1963, which would support science activities as well as spacecraft operations and in turn smooth relations between scientists and engineers. The project scientist, T. Vrebalovich, would act as an interface between the spacecraft operations team and scientists and would make decisions as to what kinds of science should be done. The counterpart was the Principal Investigator (PI), whose responsibility lay in organizing his instrument team and planning functional testing and calibration of his instrument. He and his team would assist the spacecraft operations team in planning and executing the scientific observations. Furthermore, he was cognizant of the scientific analysis and reports to NASA and the scientific community [4]. The Principal Investigator for the Ranger TV systems built by RCA, was Gerard Kuiper with his coexperimenters E.Shoemaker, H.Urey, R.Heacock and E.Whittaker. Due to previous technical and managerial problems, NASA finally received full responsibility to procure and direct modifications to the launch vehicle, as well as to the launch [4]. Every change was well planned, so that Ranger 6 would be ready for lift off in December 1963.

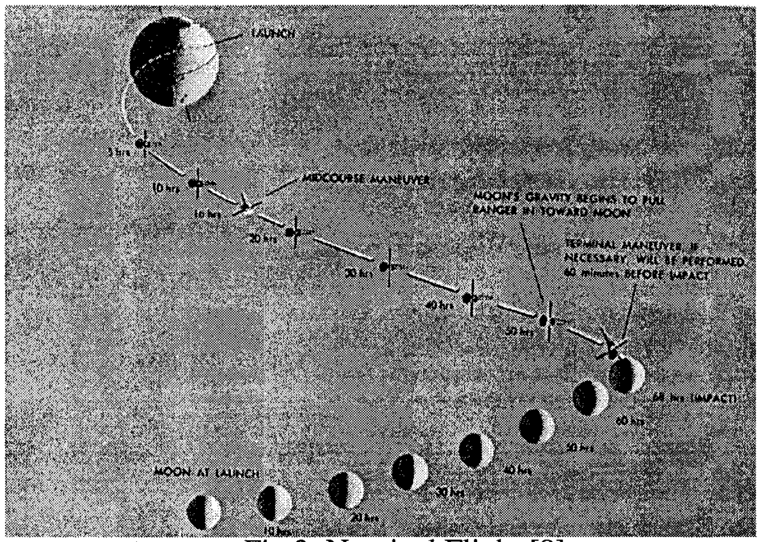

Fig.3: Nominal Flight [8]

Because of the replacement of some electrical devices, the launch date of Ranger 6 slipped to the end of January 1964. The Atlas lifted off on the morning of January 30, 1964. All systems of the rocket and the Agena upper stage worked perfectly, and their payload was carried into the expected lunar transfer orbit. The only glitch was an unexpected "power on" of the TV camera system right at plus 2 minutes after launch, when the Atlas mainstage was separated. The system turned off again inexplicably after 67 seconds. After that, all spacecraft systems worked fine, and the JPL operations team was no longer concerned. All commands on board of Ranger 6 were executed without any problems, and the spacecraft was ready to perform its midcourse maneuver a day after launch. Everything went well and JPL officials talked about a textbook flight [4]. The trajectory of Ranger 6 was set so that it would impact at the Sea of Tranquility. Media, officials, friends and families gathered together at the von Karman Auditorium, in which a JPL representative announced the latest mission information. The camera system was powered on by a timer to warm-up the instrument at minus 18 minutes before impact, which could be confirmed by analyzing the transmitted telemetry. Pitcture taking would start at impact minus 13 minutes. Goldstone was the tracking station for that part of the mission, and the cognizant operation engineers didn't receive the indication that the video system was at full power. Although everybody knew that the impact was close, an emergency command was radiated to the spacecraft. The telemetry stopped abruptly, indicating that the impact occurred. Results of the Ranger 6 mission were: 1) launch vehicle worked flawlessly, 2) spacecraft performed without any problems, 3) payload didn't transmit any science data. Media, officials and especially engineers at JPL couldn't believe it: a perfect mission, but the camera system didn't power on correctly. Several hypotheses were developed during the investigation, and it was believed that the unwanted power on of the TV systems during the launch had destroyed the high-voltage power supply to the camera system. Based on this report, RCA had to modify their camera system for the remaining Ranger flights. JPL had to change wiring to accommodate the modified camera system and it had to develop new tests in their facilities and at the Cape. Still, the single definite effect which caused the loss of the power system couldn't be found. The launch of Ranger 7 was postponed until all changes to the TV system were made and tested [3,6].

Although the press and some officials highly criticized JPL and NASA, congress and scientists agreed to continue with the Ranger project. But another failure would most likely change their support.

Modifications were made to the Atlas-Agena and Ranger 7. After they arrived at the Cape several new tests were run to ensure the correct behavior of the systems. JPL engineers moved into the new operations building, the Space Flight Operations Facility, where most flight projects were, and still are, conducted. Scientists had chosen the northern rim of the Sea of Clouds as the impact area. It provided the best conditions for picture taking. The Apollo Project Office acknowledged that area, but showed little or no interest in the decision of the landing site. The design of their landing system was almost finished, but the outcome of Ranger 7 was questionable......[4]

The launch slipped to July 28, 1964 due to technical problems much to the disappointment of personnel and media, who had again gathered at JPL's von Karman Auditorium. The actual launch and the performance of the Agena B were as expected, as well as the telemetry which was downlinked from Ranger 7. Everyone felt confident, but they were afraid to show it. After the launch, Dr. Pickering hesitated to say that the chances for a successful mission would be 50-50. But after a perfect midcourse maneuver he agreed that the chances were now 80-20. The spacecraft was in perfect condition and scientists and engineers came together to discuss the terminal maneuver, which would put the spacecraft right into it's target range and which would improve the resolution of the pictures. Knowing that Ranger 7 was on an almost perfect trajectory and wanting to minimize any possible risks, the Principal Investigator, Kuiper, and the project management came to the conclusion to cancel the last maneuver.

The TV system was powered on to warm up and to everybody's excitement telemetry showed that the camera system was fully powered. The data transmitting the science information started at minus 12 minutes to impact and were received by the DSN station Goldstone in California. At 6:25 PDT on July 31, 1964, Ranger 7 impacted on the rim of the Mare region Sea of Clouds, after sending high resolution data of the surface of the Moon for 13 minutes. "Ranger 7 was a resounding, a crashing success" [4].

The tape recorders with data from Ranger 7 were flown to the Hollywood-Burbank Airport and then, under guard, transported to JPL. At 21.00 hours Dr. Pickering and the Principal Investigator, Dr. Kuiper, presented pictures of the Moon which were a much higher quality then what was expected. The improvement in resolution in comparison to pictures taken from the Earth was expected to be 100 times better, Ranger 7 helped to improve it by the factor of 1000. 4,316 images were taken by the many different camera systems on board and these images helped scientists to discover that most of the Moon's surface was solid. One major question was answered [4].

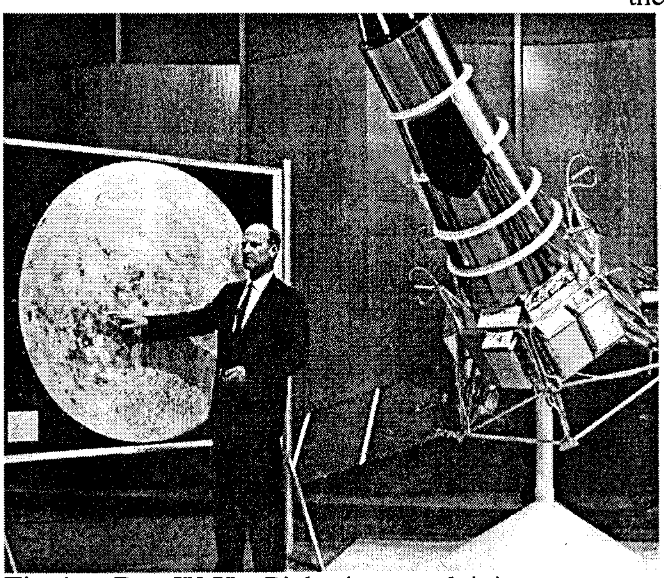

Fig.4 : Dr. W.H. Pickering explaining Ranger 7 impact site [8]

Suddenly, after the success of Ranger 7, scientists and engineers, who had stopped believing in Ranger, began to come up with various landing site options. The Apollo and Surveyor project wanted to take images of the newly created crater of Ranger 7 and other Mare regions, whereas scientists wanted to study the unknown regions of the highlands and some other unique features, such as craters.

NASA agreed to perform the Ranger 8 flight to improve the knowledge of Mare regions in support of the Apollo and the Surveyor Project. Ranger 9 would be directed to the Crater Alphonsus to satisfy requests from the scientists who supported the Principal Investigator, Dr. Kuiper.

After extensive testing, Ranger 8 was launched on February 17, 1965. All systems during the launch and during the cruise phase performed as expected, so the Principal Investigator and Project Management decided to cancel the terminal maneuver. The spacecraft impacted into the Mare Tranquillitatis region on February 20. It returned 7,137 pictures, which were outstanding once again. Ranger 9 was launched in March 1965 and also completed a perfect flight. Confident that the spacecraft worked fine, the Principal Investigator and Project Office decided to fly a terminal maneuver 30 minutes before impact, which was successful [4]. Ranger 9 crashed with a velocity of 2.671 km/sec into the Alphonsus Crater on March 24, 1965 [9]. More than 9,000 pictures were returned proving the success of the flight. It was a unique experience when the first time "real time" pictures were sent to JPL as well as around the country.

Results of the Ranger Project

The results of the Ranger Project are many and diverse. The main, but not emphasized objective was to beat the Soviets to the Moon. Therefore, many areas in the fields of engineering, science, and management had to be conquered. Block I was developed to test and prove new technology and basic science. Block II combined Block I results with a more ambitious payload for exploring the Moon. Block III and the later canceled Blocks IV and V designs gathered important information for Apollo and Surveyor. A complete new infrastructure for building, testing and operating deep space missions had to be developed, built, and certified. JPL and NASA knew that only a few of the flights would be successful. Nevertheless, engineers as well as scientists worked in the new field and tried to collaborate. The failures of Blocks I and II were learning experiences. But they were important lessons from which engineers and scientists could profit [3,6,7].

The Ranger images helped to prove the design of the landing gears of Apollo and Surveyor. The scientific results were, for that time, outstanding. Images with a resolution of better than 1000 times that of groundbased observatories, showed the variety and morphology of the lunar surface.

The Ranger Project can be summarized with the following statement: It was the precursor for all JPL deep space missions. Like Otto Lilienthal and the Wright Brothers for aviation, Ranger was the forefather for missions like Galileo, Cassini and Ulysses. Planning, testing, and operations procedures, management structure and the entire groundbased infrastructure of JPL's missions are based on the Ranger Project. We would not have today's advanced deep space program without the success and failures of the Ranger Project.

Block III Camera System:

Characteristic	Camera A	Camera B	Camera P_{1-4}
Focal length [mm]	25	76	76
Exposure time [msec]	5	5	2
Time between frames [sec]	5.12	5.12	0.84

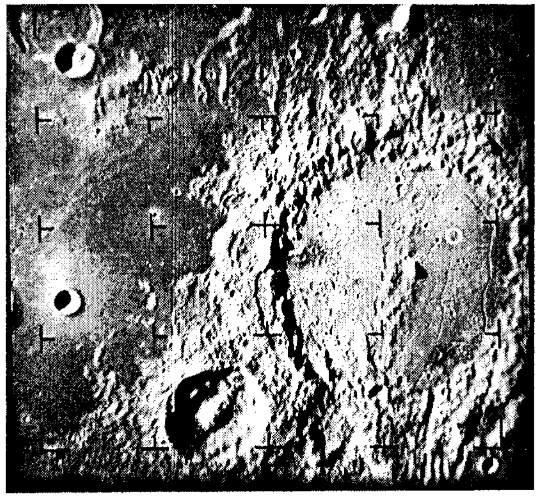

Fig.4: Ranger 9 A camera, 3min. 2 sec. before impact, distance 426 km

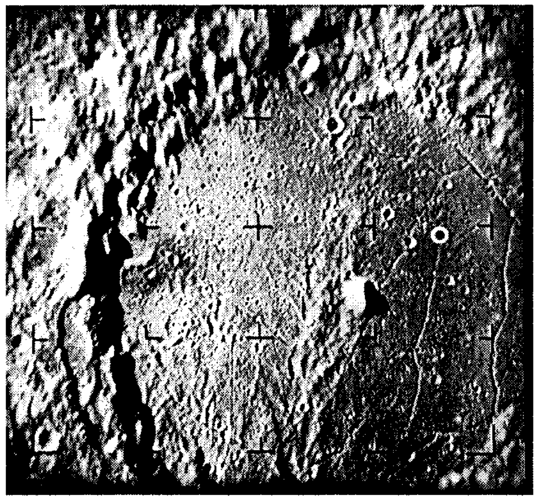

Fig.5: Ranger 9 A camera, 1min. 35 sec. before impact, distance 225 km

Fig.6: Ranger 9 A camera, 23.5 sec. before impact, distance 56 km

Fig.7: Ranger 9 A camera, 2.9 sec. before impact, distance 7.2 km

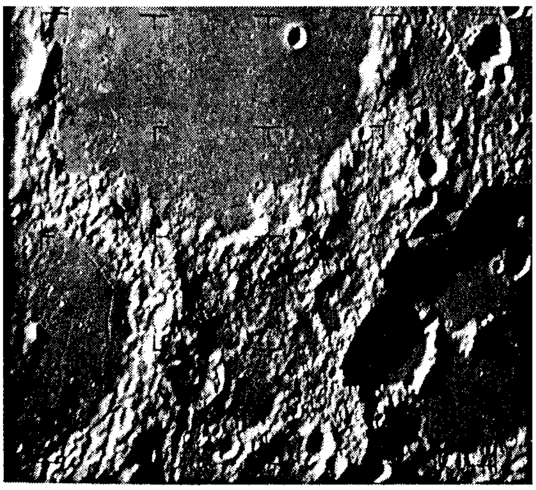

Fig.8: Ranger 9 B camera, 9 min. 29 sec. before impact, distance 1263 km

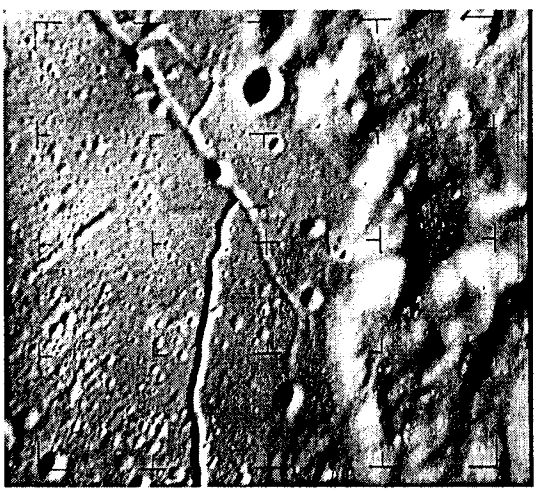

Fig.9: Ranger 9 B camera, 1 min. 12 sec. before impact, distance 172 km

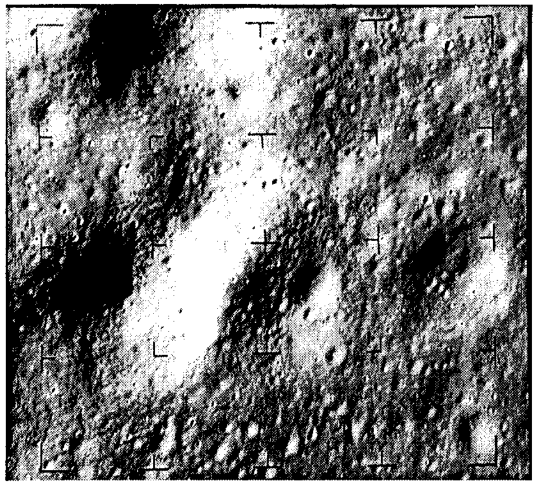

Fig.10: Ranger 9 B camera, 5.5 sec. before impact, distance 13 km

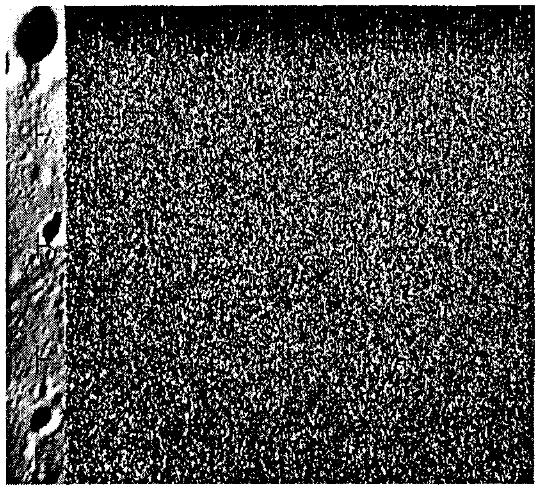

Fig.11: Ranger 9 B camera, just before impact, distance 965 m

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